12. Tools to Assess Treatment Requirements to Achieve Water Quality Standards in a Watershed

ESTIMATION OF PRE-MINING CONDITIONS FOR TRACE METAL MOBILITY IN MINERALIZED AREAS: AN OVERVIEW

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Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
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A variety of approaches have been used in the recent literature for the estimation of pre-mining (natural background) metal concentrations in areas affected by mining. The following is a list of some of these approaches: 1) historical and anecdotal data, 2) remote analogues (other similarly mineralized areas), 3) proximal analogues (nearby mineralized areas), 4) sediment sampling (streambeds, lakes, estuaries, floodplain deposits, and soil profiles, 5) stable isotopes (hydrogen, oxygen, sulfur, and carbon), 6) geochemical modeling (forward, equilibrium-based), 7) geochemical modeling (forward, kinetic- and transport-based, and inverse), 8) statistical analyses, 9) mass balance on oxygen flux, and 10) mass balance with age determination of weathered material. Examples of each approach are described and the strengths and limitations of each approach are discussed.

MODELING FREQUENCY OF OCCURRENCE OF TOXIC CONCENTRATIONS OF ZINC AND COPPER IN THE UPPER ANIMAS RIVER

Besser, J.M.; K.J. Leib

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 75-82, 1999

Scientists participating in the USGS Abandoned Minelands Initiative have quantified metal concentrations and loadings from mining-related and natural background sources in the upper Animas River of southwestern Colorado, with the goal of guiding remediation decisions by federal land-management agencies. We have compared site-specific toxicity thresholds with frequencies of dissolved metal concentrations in stream water to evaluate the contributions of zinc and copper to toxic effects in fish and aquatic invertebrates in the upper Animas. Median lethal concentrations (LC50s) of zinc and copper were determined for fathead minnows, Pimephales promelas, and amphipods, Hyalella azteca, from seven-day toxicity tests under water quality conditions typical of the upper Animas. Frequency analysis based on hysteresis models was used to predict seasonal occurrence and daily probabilities of dissolved zinc and copper concentrations at two gaging stations near Silverton, Colorado. Results of these analyses indicate that dissolved zinc concentrations at both locations
frequently exceed 7-day LC50s for amphipods, and occasionally exceed zinc LC50s for fathead minnows. In contrast, copper concentrations rarely approach lethal levels for either species. Model results are consistent with recent on-site toxicity tests with these two species. Comparison of modeled zinc and copper concentrations with published toxicity thresholds for brook trout, Salvelinus fontinalis, suggest that both zinc and copper contribute to chronic toxicity in resident trout in the upper Animas.

USE OF ECOLOGICAL INDICATORS AS ENDPOINTS FOR REMEDIATION
Boyle, Terence P.; Bob Bukantis
Science for Watershed Decisions on Abandoned Mine Lands: Review of Preliminary Results, Denver, Colorado, February 4-5, 1998
U.S. Geological Survey Open-File Report 98-297, 1998

The diagnosis of ecological health in streams is most often determined by the status of critical physical, chemical, and biological measures. Quality and condition of the benthic macroinvertebrate and fish communities have come to be the most common biological characteristics investigated as indicators of water quality. The benthic macroinvertebrate community and an array of physical and chemical variables were sampled in September 1997 in the Boulder River watershed in High Ore Creek, Cataract Creek, Basin Creek, and the Little Boulder River. Sampling was designed to assess the current status and condition of the benthic macroinvertebrate community at impacted sites and control (or reference) sites. The data collected also will provide a baseline with which to assess future change anticipated from remediation of abandoned mine lands at a number of critical sites with different levels of impact. These data will be analyzed by multivariate methods to establish the degree of differences in the structure of the benthic macroinvertebrate community among the sites and the degree to which individual environmental variables are associated with the variability observed in the structure of the benthic macroinvertebrate communities. Subsequent analysis of the biological data will include the development and application of multimetric ecological indices.

DEVELOPMENT OF A PASSIVE INTEGRATIVE SAMPLER FOR LABILE METALS IN WATER
Brumbaugh, W.G.; J.D. Petty; J.N. Huckins; S.E. Manahan
U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 93-98, 1999

A Stabilized Liquid Membrane Device (SLMD) is described for potential use as an in-situ passive integrative sampler for Cd, Cu, Ni, Pb, and Zn in natural waters. The SLMD (patent pending) consists of a 15 cm long strip of low-density polyethylene (LDPE) layflat tubing containing 1 mL of an equal mixture (v/v) of oleic acid (cis-9-octadecenoic acid) and Kelex-100® (7-[4-ethyl-1-methyloctyl]-8-quinolinol]). The reagent mixture diffuses in a controlled manner to the exterior surface of the LDPE membrane, which results in a relatively constant sequestration rate of several divalent metals for at least four weeks. Concentration factors of several thousand can be realized after just a few days allowing for extraction and quantitation of extremely low elvels of these metals by common spectroscopic methods. Data is presented for field deployment of SLMDs at two sites impacted by hard rock mining. Effects of pH and flow-rate on the SLMD sampling rate is discussed.

PRE-MINING BED SEDIMENT GEOCHEMICAL BASELINE IN THE ANIMAS RIVER WATERSHED, SOUTHWESTERN COLORADO
Church, S.E.; D.L. Fey (U.S. Geological Survey, Denver, CO); R. Blair (Ft. Lewis College, Durango, CO)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 499-512, ©2000

Determination of the pre-mining geochemical baseline in bed sediments in watersheds impacted by historical mining activity is important in establishing watershed restoration goals. Methods have been developed to solve this problem in the Animas River watershed, southwestern Colorado, using

geomorphologic mapping to identify terraces that contain pre-mining sediments. Following a systematic evaluation of possible sites, samples of pre-mining sediments in gravel deposits from 21 sites throughout the watershed were collected. Geochemical analysis of individual layers has produced a chemical stratigraphy that can be tied to the historical record through geochronological and dendochronological studies. Analysis of geochemical data, when coupled with the historical record, clearly shows that there has been a major impact on the geochemistry in bed sediments in the active stream channel by past mining activities. The pre-mining bed sediment geochemical baseline is high relative to average crustal abundance values of many metals.

DETERMINATION OF PRE-MINING GEOCHEMICAL CONDITIONS AND PALEOECOLOGY IN THE ANIMAS RIVER WATERSHED, COLORADO
Church, S.E.(U.S. Geological Survey, Denver, CO); D.L. Fey; E.M. Brouwers; C.W. Holmes; R. Blair
U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 19-30, 1999

Determination of the pre-mining geochemical baseline in bed sediments and the paleoecology in a watershed impacted by historical mining activity is of utmost importance in establishing watershed restoration goals. We have approached this problem in the Animas River watershed using geomorphologic mapping methods to identify old pre-mining sediments. A systematic evaluation of possible sites resulted in collection of a large number of samples of pre-mining sediments, overbank sediments, and fluvial tailings deposits from more than 50 sites throughout the watershed. Chemical analysis of individual stratigraphic layers has resulted in a chemical stratigraphy that can be tied to the historical record through geochronological and dendochronological studies at these sites.

DISCRIMINATING BETWEEN BACKGROUND AND MINE-IMPACTED WATERS
Davis, A.; A. Tisdale (Geomega, Boulder, CO); C. Byrns (BHP Robinson, Ely, NV)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 473-484, ©2000

The Robinson district, Ely, NV, is a hydrogeologically complex system with several distinguishable geologic blocks, each with a distinct background groundwater chemisty. To discriminate between background and mine-impacted groundwater, background wells, monitoring wells, pit lakes, waste rock seeps, and surface water samples were analyzed for a suite of major cations and anions, together with trace and precious metals, rare earth elements, 2H-deuterium and 18O/16O. The data allowed identification of groundwater flow paths, verification of hydrochemical source areas and characterization of natural attenuation mechanisms (e.g., mixing, dilution, and mineral precipitation) that control the concentration and migration of metals at the site.

A MINI DRIVE POINT SAMPLER FOR MEASURING PORE WATER SOLUTE CONCENTRATIONS IN THE HYPORHEIC ZONE OF SAND-BOTTOM STREAMS
Duff, J.H.; F. Murphy; C.C. Fuller; F.J. Triska; J.W. Harvey; A.P. Jackman
Limnology and Oceanography, Vol 43 No 6, p 1378-1383, 1998

A new method for collecting pore-water samples in sand and gravel streambeds is presented. We developed a mini drivepoint solution sampling (MINIPOINT) technique to collect pore-water samples at

2.5-cm vertical resolution. The sampler consisted of six small-diameter stainless steel drivepoints arranged in a 10-cm-diameter circular array. In a simple procedure, the sampler was installed in the streambed to preset drivepoint depths of 2.5, 5.0, 7.5, 10.0, 12.5, and 15.0 cm. Sampler performance was evaluated in the Shingobee River, Minnesota, and Pinal Creek, Arizona, by measuring the vertical gradient of chloride concentration in pore water beneath the streambed that was established by the uninterrupted injection to the stream for 3 d. Pore-water samples were withdrawn from all drivepoints simultaneously. In the first evaluation, the vertical chloride gradient was unchanged at withdrawal rates between 0.3 and 4.0 ml min^{-1} but was disturbed at higher rates. In the second evaluation, up to 70 ml of pore water was withdrawn from each drivepoint at a withdrawal rate of 2.5 ml min^{-1} without disturbing the vertical chloride gradient. Background concentrations of other solutes were also determined with MINIPOINT sampling. Steep vertical gradients were present for biologically reactive solutes such as DO, NH_{+4}, NO_{-3}, and dissolved organic C in the top 20 cm of the streambed. These detailed solute profiles in the hyporheic zone could not have been determined without a method for close interval vertical sampling that does not disturb natural hydrologic mixing
between stream water and groundwater.

SYNTHESIS OF WATERSHED CHARACTERIZATION FOR MAKING REMEDIATION DECISIONS

Kimball, Briant A.(U.S. Geological Survey, Salt Lake City, UT); Kenneth E. Bencala; John M. Besser

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 3-8, 1999

The Abandoned Mine Lands Initiative combines expertise from each division of the U.S. Geological Survey. The watershed orientation of the initiative leads to a synthesis of information from many areas of study. Geologic and geochemical studies contribute information about mineral deposits, their role in premining conditions, and their potential for contributing metals to mine drainage. Hydrologic and geochemical studies indicate the transport and transformation of metals from the sources to the streams. Biological studies show the effects of metals on the aquatic organisms and habitats, and help to establish goals for improving the habitats. All of these studies are unified by the application of geographic information systems and information management methods to enable a synthesis for regulatory and land management agencies.

QUANTIFYING EFFECTS OF METAL LOADING FROM MINE DRAINAGE

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Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1381-1390, ©2000

Thousands of abandoned and inactive mines are located in environmentally sensitive mountain watersheds. Cost-effective remediation of mining sites in these watersheds requires knowledge of the most significant sources of metals to surface waters. The significance of a given source not only depends upon the concentrations of a toxic metal, but also on the total mass, or load of metal added to the stream. To determine loads, tracer-injection methods were combined, to provide reliable discharge measurements on a watershed scale, with synoptic sampling, to provide spatially detailed concentration data. The resulting load profiles indicate which sources have the greatest effect on streams, where natural attenuation of metal loads

occurs, and where ground-water inflows are located. This is part of the information needed for planning remediation of mine-drainage effects. The approach is illustrated by comparing zinc loading curves from three watersheds affected by mine drainage.

USE OF TRACER-INJECTION AND SYNOPTIC-SAMPLING STUDIES TO QUANTIFY EFFECTS OF METAL LOADING FROM MINE DRAINAGE
Kimball, B.A. (U.S. Geological Survey, Salt Lake City, UT); R.L. Runkel; K.E. Bencala; Katherine Walton-Day
U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 31-36, 1999

Thousands of abandoned and inactive mines are located in environmentally sensitive mountain watersheds. Cost-effective remediation of the effects of metals from mining in these watersheds requires knowledge of the most significant sources of metals. The significance of a given source not only depends on the concentration of a toxic metal, but also on the load (or mass) of metal added to a stream. An approach that has worked well for mountain watersheds combines tracer-injection methods, to provide reliable discharge measurements on a watershed scale, with synoptic sampling, to provide spatially detailed concentration data. Multiplying concentration and discharge gives a profile of sampled instream load from which we calculate a cumulative sum of load along a study reach. Part of that cumulative total load that can be attributed to visible inflows, and another calculation gives a maximum load due to visible inflows. Comparisons of these different views of load profiles provide important characteristics of a stream that are useful for remediation planning.

COMPARISON OF SURFACE-WATER CHEMISTRY IN UNDISTURBED AND MINING-IMPACTED AREAS OF THE CEMENT CREEK WATERSHED, COLORADO
Mast, M. Alisa; Winfield G. Wright; Kenneth J. Leib
U.S. Geological Survey Open-File Report 98-297, 1998

Many tributaries in the upper Animas River watershed are acidic and have elevated concentrations of dissolved metals as a result of historical mining and natural weathering of mineralized volcanic rocks. To gain a better understanding of the relative importance of natural-background and mining-related sources of dissolved metals, more than 70 streams, springs, and draining adits were sampled during summer 1997 in the Cement Creek watershed, a 50-square-kilometer subbasin of the upper Animas River. Although prospect pits and abandoned mines are scattered throughout the study area, much of the watershed, particularly at higher elevations, is relatively undisturbed. Preliminary results indicate that natural-background and mining-impacted areas of the basin produce acidic and neutral surface water, however, concentrations of major ions and dissolved metals generally are higher at the impacted sites than at the natural-background sites. The median pH of samples collected at the mining-impacted sites was 4.28 (range 2.79 to 7.32) compared to the median value of 6.59 (range 2.97 to 7.96) at the natural-background sites. Sulfate concentrations at the sampling sites ranged from 1 to 450 milligrams per liter (mg/L) and were generally higher at the mining-impacted sites (median value 138 mg/L) than at the background sites (median value 56 mg/L). Dissolved zinc concentrations were highly variable among the sampling sites, ranging from <10 to
14,600 micrograms per liter (µg/L). Results from the natural-background springs and streams revealed a geographic pattern in surface-water chemistry that appears to be related to the degree of bedrock alteration. The eastern part of the basin is primarily underlain by propylitically altered lavas, which produce neutral

surface water (pH 6.40 to 7.96) with relatively low concentrations of dissolved metals, except for zinc (as much as 230 µg/L). The western part of the basin is more intensely altered than the eastern part, and includes pervasive argillic-type alteration in the northwest quadrant and quartz-sericite-pyrite alteration localized along structures. Water draining these areas is more acidic (pH ranging from 3.25 to 4.61) and has elevated concentrations of dissolved metals. The results of this
study should provide useful information for establishing water-quality standards and characterizing sources of metals loads for surface waters in the upper Animas River Basin.

AQUATIC PHYSICAL HABITAT AND HYDROLOGY IN ABANDONED MINED LAND STUDIES
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U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 47-54, 1999

Abiotic and non-chemical factors may limit the ability of a stream to respond to improvements in traditional water quality parameters because physical habitat and sediment characteristics may also limit the populations of aquatic animals. A reach of the Upper Animas River in southwestern Colorado is analyzed to show possible limits caused by physical habitat and sediment. Habitat for trout in the Animas River near Howardsville may be limited by high streamflows (because of high velocities) and by winter conditions (by velocities too high for winter habitat needs and low depths). The characteristics of the substrate (bed material) may offset the impacts of high velocities in the spring and the depths and velocities in the winter. The characteristics of the sediment in the river limit the winter habitat. In the river below Howardsville, large rocks provide shelter to trout during winter and spring runoff; fewer velocity shelters are available above Howardsville. Spawning gravels are available in the river below Howardsville but these gravels occur above the water surface of the fall spawning flows, but would be covered by spring spawning flows. Taken as a whole, it is expected the numbers and sizes of the fish would be larger below Howardsville than above if the number and size of velocity shelters is the only factor limiting fish populations. If the location of the spawning gravels is also a limiting factor, then the river spawning fish would be spring spawners, such as cutthroat trout. There are beaver ponds upstream of Howardsville that may provide fall spawning habitat for brook trout. An informal goal for the Upper Animas River is to establish a brown trout fishery. This is not a desirable goal because: (1) brown trout require that 50–70% of the river be pools and that the river must be shaded, however, there are few pools in the subject reach; and (2) brown trout spawn in the fall but the spawning gravels are high in the cross section where they can only be used by spring spawners. The existing Animas River requires a trout that can use the substrate in the main channel as habitat during most of the year. The trout most adapted to a river with few pools and gravel/cobble/rubble substrate is the brook trout. Cutthroat trout could also use the river because spawning gravels are available during spring runoff.

CHARACTERIZATION OF METALS IN WATER AND BED SEDIMENT IN TWO WATERSHEDS AFFECTED BY HISTORICAL MINING IN MONTANA AND COLORADO

Nimick, D.A. (U.S. Geological Survey, Helena, MT); S.E. Church; T.E. Cleasby; D.L. Fey; B.A. Kimball; K.J. Leib; M.A. Mast; W.G. Wright

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 11-18, 1999

Characterization of metals in water and bed sediment is essential for planning effective and cost-efficient remediation in watersheds affected by historical mining. To aid cleanup efforts on Federal land, pilot investigations that are part of the USGS Abandoned Mine Lands Initiative are being conducted in two watersheds in Colorado and Montana. Assessment of ore-related metals and other trace elements in water and sediment in these watersheds provides information to delineate stream reaches having elevated metal concentrations, determine sources of contaminated material, understand the transport of dissolved and particulate metals, and evaluate the potential for metal toxicity to biota.

CONSIDERATIONS OF OBSERVATIONAL SCALE WHEN EVALUATING THE EFFECT OF, AND REMEDIATION STRATEGIES FOR, A FLUVIAL TAILINGS DEPOSIT IN THE UPPER ARKANSAS RIVER BASIN, COLORADO

Smith, K.S.; Katherine Walton-Day; J.F. Ranville

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 131-138, 1999

We examined the water-quality effects of a fluvial tailings deposit along the flood plain of the upper Arkansas River south of Leadville, Colorado. Fluvial tailings deposits are a possible diffuse source of acid and metal contamination to surface and ground water. We used four different scales of observation to evaluate the potential effect of fluvial tailings on water quality. First, we collected surficial material and subjected it to batch water-leaching tests. Second, we excavated an intact 8-inch-diameter (60 centimeters in length) core, leached it under unsaturated conditions for 23 days, and collected the effluent. Third, we examined the water quality of the shallow ground water beneath the fluvial tailings deposit; and fourth, we monitored water quality along a 5-kilometer reach of the adjacent Arkansas River. Our results illustrate the importance of observational scale in the interpretation of the effect of the fluvial tailings deposit on water quality. Leaching of surficial samples indicates that there is a large reservoir of readily water-soluble material yielding elevated metal concentrations and high acidity that could degrade water quality. However, the river-water-quality data indicate that there is no measurable effect from the fluvial tailings deposit. It is important to note that this data set does not include any stormwater sampling. Natural attenuation processes (including
dilution) appear to contribute to our different findings at different observational scales. Attention to the importance of observational scale can lead to informed remediation decisions. More Info: http://toxics.usgs.gov/pubs/wri99-4018/Volume1/index.html

OVERVIEW OF RARE EARTH ELEMENT INVESTIGATIONS IN ACID WATERS OF U. S. GEOLOGICAL SURVEY ABANDONED MINE LANDS WATERSHEDS

Verplanck, P.L.; D.K. Nordstrom; H.E. Taylor

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 83-92, 1999

The geochemistry of rare earth element (REE) variations in acid waters is being studied as part of the U. S. Geological Survey Abandoned Mine Lands Initiative in two pilot watersheds, upper Animas, Colorado and Boulder, Montana. The following objectives are under investigation: (1) comparison of acid mine waters and naturally acidic springs, (2) determination of whether the dominant control on REEs in acid waters is source-related or post-dissolution process-related, (3) determination of the role of iron and aluminum colloid formation on the REE patterns, (4) address the utility of REE geochemistry in acid waters as an analogue for the actinides, and (5) produce a Standard Reference Water Sample for REEs. Results demonstrate that the REE concentrations in acid waters increase with decreasing pH but tend to be two to three orders of magnitude lower than ore elements such as Cu and Zn. REE patterns are generally convex-up for waters in the upper Animas, and they are nearly flat with a negative europium anomalies for waters in the Boulder basin. These results reflect predominantly source-related signatures. Natural acid springs are frequently, but not consistently, characterized by a negative Ce anomaly that may be process-related. Field and laboratory experiments indicate that dissolved REEs are affected by iron and aluminum colloid formation but sorption or coprecipitation with aluminum at pH values greater than 4.5 is stronger than with iron. Uranium and thorium, however, show a tendency to be removed from solution more strongly at lower pH (3-4) values, consistent with expected differences in oxidation state and a stronger affinity for iron precipitation.

GEOMORPHOLOGICAL CONTEXT OF METAL-LADEN SEDIMENTS THE ANIMAS RIVER FLOODPLAIN, COLORADO

Vincent, K.R.; S.E. Church; D.L. Fey

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 99-105, 1999

The watershed of the upper Animas River in the San Juan Mountains of Colorado was the site of extensive mining and ore milling during the late 19th and early 20th centuries. Using geologic mapping, stratigraphic and sedimentological studies of floodplain sediments, geochronology, historical records, and geochemical analysis of sediments, we conclude the following. Prior to mining, the river valley below the town and ore mill site of Eureka was composed of small, multi-thread, gravel bedded channels. These were located within a silty floodplain consisting of willow thickets and possibly intermittent and localized beaver ponds. A radical change in the stream and floodplain environment started sometime around the turn of the century and concluded with aggregation and burial of older sediments with sheets of gravel. This was caused by ore milling, not mining or other activities. Mills in and near Eureka supplied huge quantities of tailings to the river, at rates 50 to 4,700 times greater than the natural (pre-mining) production of sediment from hillslopes. Floodplain sediments have naturally high zinc concentrations of about 1000 parts per million, but ore milling resulted in an increase of zinc concentrations by as much as an order of magnitude. Using vanadium as a lithologic tracer for sediment derived from natural erosion of the watershed, we estimate that the fine fraction of streambed and floodplain sediments deposited after 1900 A.D. contain, in general, two-thirds tailings and one-third natural sediments.

APPLICATION OF THE SOLUTE-TRANSPORT MODELS OTIS AND OTEQ AND IMPLICATIONS FOR REMEDIATION IN A WATERSHED AFFECTED BY ACID MINE DRAINAGE, CEMENT CREEK, ANIMAS RIVER BASIN, COLORADO

Walton-Day, Katherine; R.L. Runkel; B.A. Kimball; K.E. Bencala

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 37-46, 1999

The solute-transport model OTIS and the reactive solute-transport model OTEQ were used to simulate geochemical conditions in Cement Creek, a tributary to the Animas River in southwestern Colorado. Results with OTIS indicated that removal of iron and zinc is required to simulate observed stream conditions on September 20, 1996. Two remediation scenarios that depicted remediation of lesser and greater amounts of zinc from Prospect and Ohio Gulches and the May Day Dump indicated that these actions would reduce zinc concentrations at the mouth of Cement Creek by 7 percent and 13 percent, respectively. OTIS simulations do not account for the effects of changing stream pH on metal concentrations. OTEQ is used to quantify these effects. Preliminary OTEQ simulations indicated that precipitation of ferrihydrite improved the agreement between simulated and observed pH in the mixing zone of Illinois Gulch and Cement Creek. However, observed zinc removal in this zone was not successfully simulated due to the spatial nature of the mixing process and lack of data about the identity and thermodynamic properties of precipitates forming in the mixing zone. Use of OTEQ to simulate remediation requires a better understanding of the processes that occur in streams affected by acid mine drainage.

OXYGEN ISOTOPES OF DISSOLVED SULFATE AS A TOOL TO DISTINGUISH NATURAL AND MINING-RELATED DISSOLVED CONSTITUENTS

Wright, W.G. (U.S. Geological Survey, Durango, CO); D.K. Nordstrom

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 67-74, 1999

Natural and mining-related dissolved-constituent concentrations need to be distinguished in a watershed affected by abandoned mines to prioritize subbasins for remediation and to assist with the establishment of water-quality standards. The oxygen isotopes of dissolved sulfate can be used to distinguish between natural and mining-related sources of dissolved constituents. Several methods employing the oxygen isotopes of dissolved sulfate can be used to determine the relative amounts of natural and mining-related dissolved constituents in water: (1) the isotope-dilution equation for simple mixing zones (two sources and one receiving stream); (2) the isotope mass-balance equation for streams receiving dissolved sulfate from multiple geologic sources; and (3) graphical relations and the mathematical solution of simultaneous equations in a watershed approach. Using the different methods for data collected during low flow, about 71 to 75 percent of the dissolved-constituent concentrations are from natural sources in selected subbasins of the upper Animas watershed.